AD-A119 185 CINCINNATI UNIV OH DEPT OF MATERIALS SCIENCE AND MET--ETC F/G 11/6
ELEVATED TEMPERATURE LOW CYCLE FATIGUE OF NICKEL BASE SUPERALLO--ETC(U)
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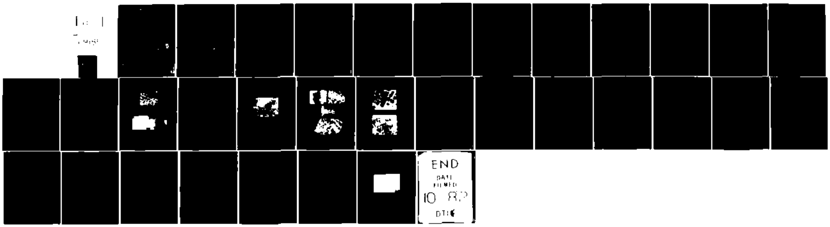

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Nickel Base Superalloys, René 80, conventionally cast, directionally solidified, single crystal, high temperature low cycle fatigue, optical microscopy, scanning electron microscopy, transmission electron microscopy.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

High temperature low cycle fatigue (LCF) has been studied for directionally solidified (DS) and conventionally cast (CC) René 80. It was found that the LCF behavior of the DS material is in reasonable accord with an approach developed previously by the author in which the life is determined by a trade-off between environmental degradation and beneficial structural coarsening.

The LCF life depends on the location in the ingot (top, middle or bottom) as well as on the orientation (lon- (continued)

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gitudinal, transverse, 45 deg). The location dependence can be explained in terms of the tendency to form a script-like carbide morphology, which is most pronounced in the middle, and a modulus effect. The modulus in the middle was intermediate between the bottom (high) and top (low) and for a plastic-strain controlled LCF test led to a rather large elastic strain component. The combination of high total strain range and deleterious carbide morphology reduced the fatigue life. By similar reasoning, the life was a maximum near the bottom even though the misorientation was greatest in this region.

For the CC René 80 it was shown that the best data correlation was obtained by using total strain range for tests carried out at 75°F. This representation is consistent with the carbide-induced crack formation which was observed metallographically.

I. Introduction

This project has been in progress for 2 years as of Jan 1, 1982 and is primarily concerned with the low cycle fatigue (LCF) behavior of directionally solidified (DS) René 80. In addition some LCF studies have been carried out using conventionally cast (CC) René 80. Results obtained since the last program report are described in the following sections.

II. Program Results June 1981 - December 1981

A. Directionally Solidified René 80

1. Background

The LCF behavior of DS René 80 has been studied in the temperature range 75-1600°F. All tests were carried out using longitudinal specimens in the total strain control mode with periodic adjustments to maintain the plastic strain range constant. The cycle character was nominally zero-tension-zero ($A_\varepsilon = \Delta\varepsilon/\bar{\varepsilon} \simeq 0.95$).

The gage sections of the smooth bar specimens were machined from DS ingots in the longitudinal, transverse and 45° orientations. Specimens were identified as to their location (top, middle & bottom) in the DS bar such that each specimen could be placed in a definite position in the original ingot. In the present reporting period, emphasis was placed on analysis and microscopy studies as described below.

2. LCF at 75°F

In Fig. 1, a Coffin-Manson plot is given showing both DS and CC René 80. While the scatter is significant, this plot provides some evidence that the LCF lives of the DS alloy are superior

to those of the CC alloy at a plastic strain range of 0.2%. However, the lives of both the DS and CC alloys tended to fall within the same scatter band at a plastic strain range of 0.1%. Further testing will be carried out using longitudinal specimens which are expected to show the longest lives.

3. Effect of Temperature on LCF Behavior

The LCF behavior of transverse specimens was studied over the temperature range 75°F-1600°F at a plastic strain range of 0.1%. The results are drawn in Fig. 2 where they are compared to the 45° specimen data given in the previous report. It can be seen that the LCF life decreases up to about 1400°F for both orientations after which it increases at 1600°F to a level higher than that observed at room temperature. Specimens were subsequently metallographically examined and the following observations were made:

i) Up to 1400°F, well-developed slip bands were present as seen in Fig. 3

ii) Specimens tested at 75°F and 800°F showed at higher dislocation density in the slip bands compared to 1400°F.

iii) Precipitate shearing by the dislocations was observed at 75°F as seen in Fig. 4.

iv) At 1400°F slip-band broadening was observed implying a larger component of thermally activated cross slip than was seen at the lower temperatures. This conclusion is borne out by the tensile data shown in Fig. 5 where it can be seen that the yield stress starts to drop off rapidly after 1400°F. Such behavior is expected since the γ' precipitate has a maximum strength in the temperature range 1450-1550°F. Dislocation substructures at 1400°F

are seen in Fig. 6.

v) For those specimens tested at 1600°F, no planar slip bands were observed and the γ' precipitates had significantly coarsened, showing interfacial dislocations at the γ/γ' interface similar to observations made for conventionally cast René 80.[1,2] The dislocation substructure is shown in Fig. 7.

The experimental observations are compatible with the idea that the life is determined by the accumulation of dislocation debris at 75°F. As the temperature increases the environment becomes increasingly important and the life decreases until at some point, around 1600°F, the γ' precipitates begin to coarsen. Above 1600°F the stress in a strain controlled cycle decreases rendering the oxidation less effective in causing failure. In other words the tradeoff between environmental damage and structure coarsening (which is beneficial) is biased in favor of structural coarsening.

Such behavior is apparently compatible with the approach developed previously under the auspices of this program in which crack initiation occurs when the following equation is obeyed:[1,2]

$$\sigma_{max}^{i} \cdot \ell_i = Co \qquad \ldots (1)$$

where σ_{max}^{i} = maximum stress in fatigue cycle at initiation

ℓ_i = relative depth of oxygen penetration

Co = constant

Experimental data was used to check the validity of this approach for all specimens tested at 1600°F and the results are shown in Figs. 8-10. It can be seen that the data correlates reasonably

well to eq. 1 and that there is a further improvement when the correlation is made in terms of $\Delta\sigma$ rather than σ_{max}. It is also noteworthy that the best correlation was obtained for the 45° specimens. Reasons for this behavior are being explored.

At 1600°F, testing was carried out for plastic strain ranges from 0.02% to 0.25% and the results are shown in Figs. 11-13. For transverse specimens, Fig. 11, the life depends on location in the ingot, at least for the highest plastic strain range (0.25%). The lowest life was for specimens taken from the middle while the largest life was associated with specimens taken from the bottom. A similar trend was observed for the longitudinal specimens at all strain ranges, Fig. 12. An insufficient number of 45° tests were run to draw any conclusions as to the effect of location. The dependence of life on location, at least for the longitudinal specimens can be explained on the basis of modulus and a tendency to form a script-like carbide. The modulus as a function of location is shown in Fig. 14 by the set of graphs on the lefthand side. The modulus decreases from bottom to top for the longitudinal specimen. This can be understood in terms of the average orientation becoming closer to [001] near the top. The [001] direction is, of course, "soft" and for a given plastic strain range, the elastic component will be greater the closer the [001] direction is to the stress axis. Thus near the middle, the total strain is large for a given plastic strain range (as seen on the graph on the right) and the tendency to form script-like carbides is also high. These two factors (high total strain and undesirable structure) act so as to minimize the life. On the other hand, near the bottom the modulus is high (meaning that the elastic

component will be low) and there is also little tendency to form script-like carbides. Both of these factors act in such a way as to increase the life. The effect of modulus and carbide structure on the LCF life is summarized in Table 1.

B. Conventionally Cast René 80

It has been shown in the previous report to the AFOSR that the LCF data at 75°F and 800°F exhibited considerable scatter when the data were represented in terms of a Coffin-Manson plot. It was furthermore shown that crack initiation was generally associated with carbides and that the data fell into two groups: a long life group in which there was evidence of slip band formation and a short life group in which flip bands were rarely seen. If carbide cracking is the controlling event during low temperature LCF, then the life would be expected to correlate better with the <u>total</u> strain than with the <u>plastic</u> strain, since the total strain is an indication of the displacement to which carbides would be subjected. The lives at 75°F, 800°F and 1400°F are shown in Figs. 15-20 in terms of both plastic strain range and total strain range. For 75°F there is a significant improvement when the data are represented in terms of total strain, indicative of a critical displacement criterion for cracking. At 800°F and 1400°F both total strain range and plastic strain range provide equally precise representations of the data.

Additional metallography was carried out to further characterize the crack formation process and an excellent example of carbide cracking can be seen in Fig. 21. It is clear that carbide cracking and not decohesion is the operative process and that the carbide, not the carbide/matrix interface is the weak link.

III. Personnel

In addition to the Principal Investigator, one full-time Research Engineer, one Ph.D. Research Assistant, one part-time M.S. student, one sophomore lab assistant and one senior thesis research student have been associated with this project. Consultation on the solidification aspects of the project has been supplied by Mr. C. Wukusick of G.E. who has continued to supply DS and XL materials free of charge. Brazing and heat treatment was also done at G.E. at no charge to the project and was arranged by P. Domas. Details of the involvement of all research personnel associated with the project are given in Table II. Some secretarial and technician support has been provided by the Department of Materials Science and Metallurgical Engineering at no cost to the project.

IV. Reporting Activities

A. Theses and Dissertations

1. Paul A. Domas: "An Investigation of Notch Low Cycle Fatigue Life Behavior of René 80 at High Temperature," Ph.D. Dissertation, University of Cincinnati, June 1981.

2. Amit Prakash: "Low Cycle Fatigue Behavior of the Directionally Solidified Nickel Base Superalloy René 80," Ph.D. Dissertation, University of Cincinnati, Dec. 1981.

3. Bruno S. Boursier: "Evaluation of Damage Mechanisms in the Ni Base Superalloy René 80 Under Low Cycle Fatigue in the Temperature Range 75°F-1400°F," M.S. Thesis, University of Cincinnati, Dec. 1981.

4. Kevin J. McCurdy: "The Influence of Orientation and Environment on the LCF Life of Directionally Solidified René 80," B.S. thesis, University of Cincinnati, June 1981.

B. Presentations at 1981 Fall AIME Meeting – Louisville, Ky, Oct. 12, 1981

1. P. A. Domas and Stephen D. Antolovich: "Notch LCF Behavior at Elevated Temperature."

2. B. Boursier and Stephen D. Antolovich: "Evaluation of Damage Mechanisms at Intermediate Temperature in René 80."

3. A. Prakash, K. McCurdy and Stephen D. Antolovich: "High Temperature Fatigue Studies of DS René 80."

C. Papers

Papers based on the M.S. theses and Ph.D. dissertations are in various states of preparation and are listed below:

1. A. Prakash, K. McCurdy and Stephen D. Antolovich: "High Temperature LCF Studies of DS René 80 – Microstructural Effects." Final draft has been written and is being reviewed by co-workers before submission to journal.

2. P. A. Domas and Stephen D. Antolovich: "A Mechanistically Based Model for High Temperature Notched LCF of Uncoated Nickel-Base Superalloys." First draft is written and is being typed for internal review.

3. P. A. Domas and Stephen D. Antolovich: "An Integrated Local Energy Density Approach to Notch LCF Life Prediction." First draft is written and is being typed for internal review.

It is anticipated that all of these papers will be submitted for formal review by July 1982. In addition, a paper will be prepared from the M.S. thesis of B. Boursier and that should be written by Sept. 1982.

V. Interactions with other AFOSR Principal Investigators and AF Personnel

The author has maintained contact with other OSR PI's (Pelloux, Weertman) exchanging publications, reports and information on an informal basis during technical meetings. For example, information has been sent to J. Weertman on precipitate coarsening and she has provided references on the same phenomena where the SANS technique was used.

References

1. Stephen D. Antolovich, S. Liu and R. Baur: A Mechanistically Based Model for High Temperature LCF on Ni Base Superalloys. "Superalloys 1980", Eds. Tien, Wlodek, Gell and Naurer. ASM 1980, pp. 605-613.

2. Stephen D. Antolovich, S. Liu and R. Baur: Low Cycle Fatigue Behavior of René 80 at Elevated Temperatures. Met. Trans., Vol. 12A, 1981, pp. 473-481.

3. Stephen D. Antolovich, P. Domas and J. L. Strudel: Low Cycle Fatigue of René 80 as Affected by Prior Exposure. Met. Trans., Vol. 10A, 1979, pp. 1859-1868.

TABLE I

EFFECT OF MODULUS AND STRUCTURE ON LCF LIFE OF LONGITUDINAL AND TRANSVERSE SPECIMENS.

LOCATION	MODULUS	$\Delta\epsilon_t$ (for a given $\Delta\epsilon_p$)	TENDENCY TO FORM SCRIPT MC CARBIDE	RELATI[illegible] LIFE (for a [illegible]ven orient[illegible])
TOP	LOW	HIGH	INTERMEDIATE	INTERMEDIATE
MIDDLE	INTERMEDIATE	INTERMEDIATE	HIGH	LOW
BOTTOM	HIGH	LOW	LOW	HIGH

Table II

Participants in AFOSR 80-0065
June 1 - Dec 31, 1981

Name	Nature of Participation	Dates
Stephen D. Antolovich	Principal Investigator	1/1/80-
B. Boursier	Research Engineer/M.S. student	1/1/80-12/31/81
A. Prakash	Ph.D. Student	1/1/80-11/30/81
K. McCurdy	M.S./B.S. thesis student	9/6/80-
C. Wukusick	General Electric employee – has supplied DS and XL René 80	1/1/80-
J. Wukusick	B.S. senior thesis student	9/28/81-
K. Hemker	Laboratory assistant	6/1/81-

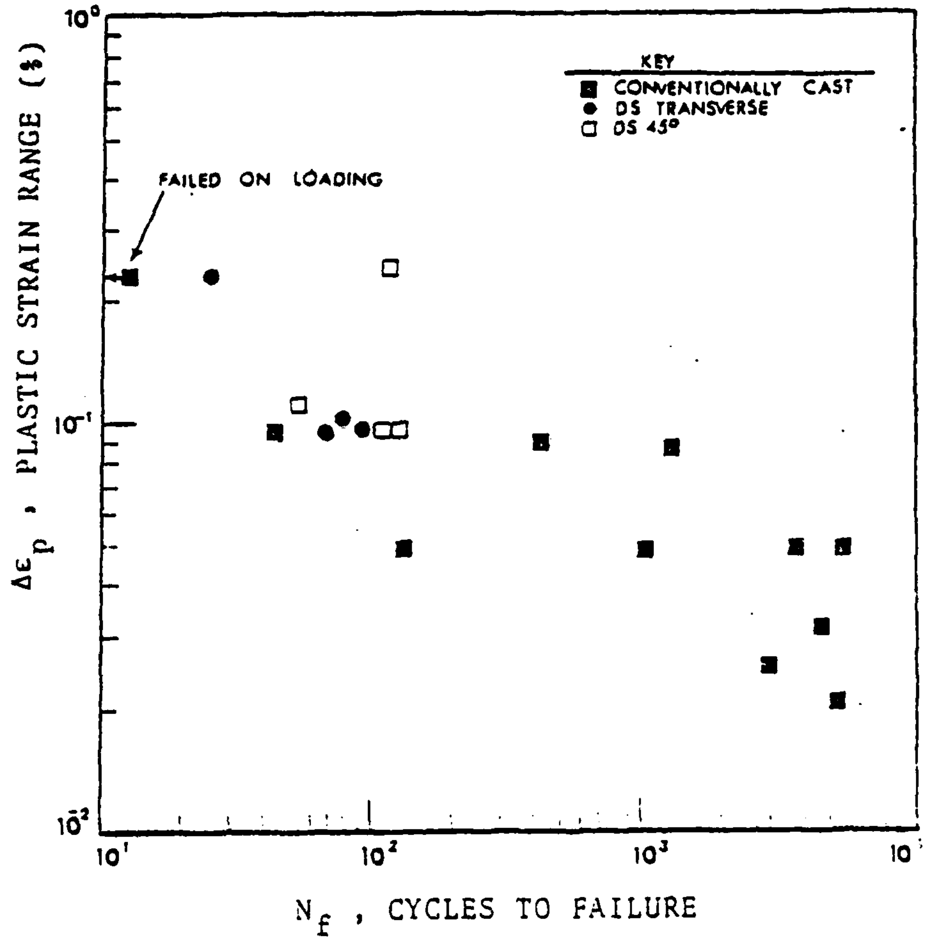

Fig. 1. Coffin-Manson plot of room temperature (75F) DS and CC Rene-80 data.

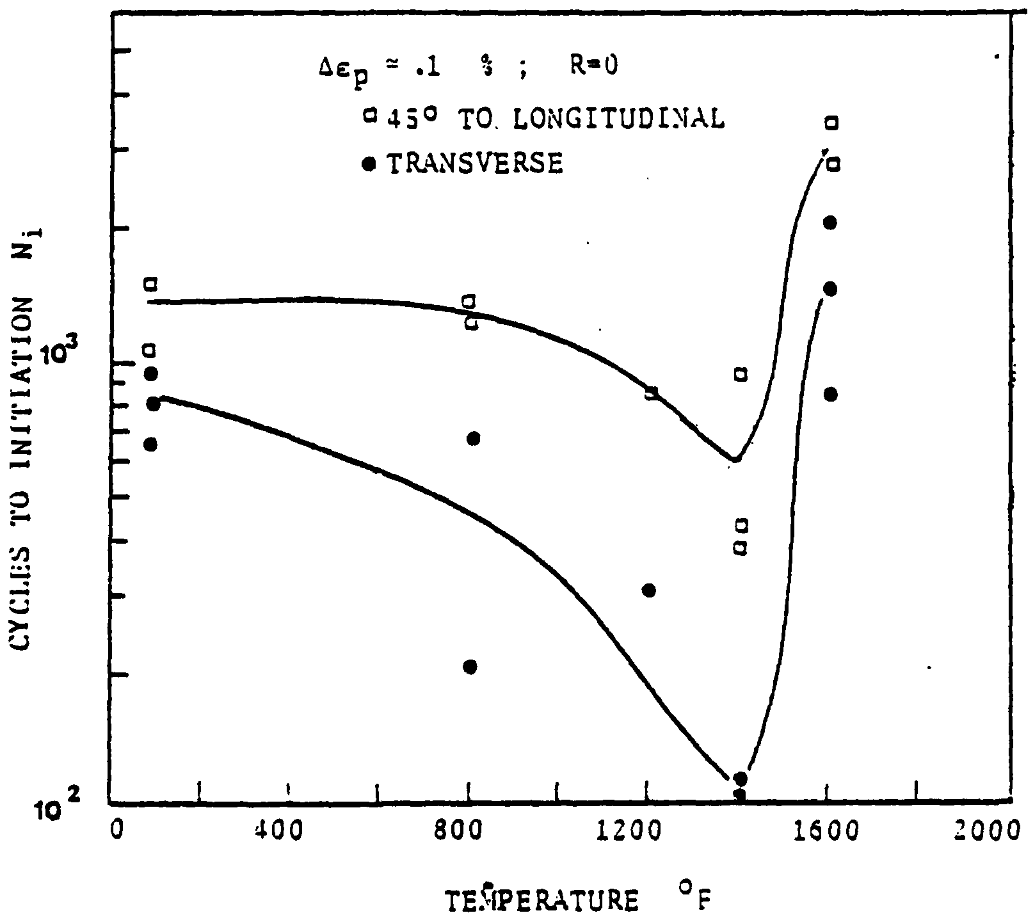

Fig. 2. Cycles to initiation vs temperature for DS René

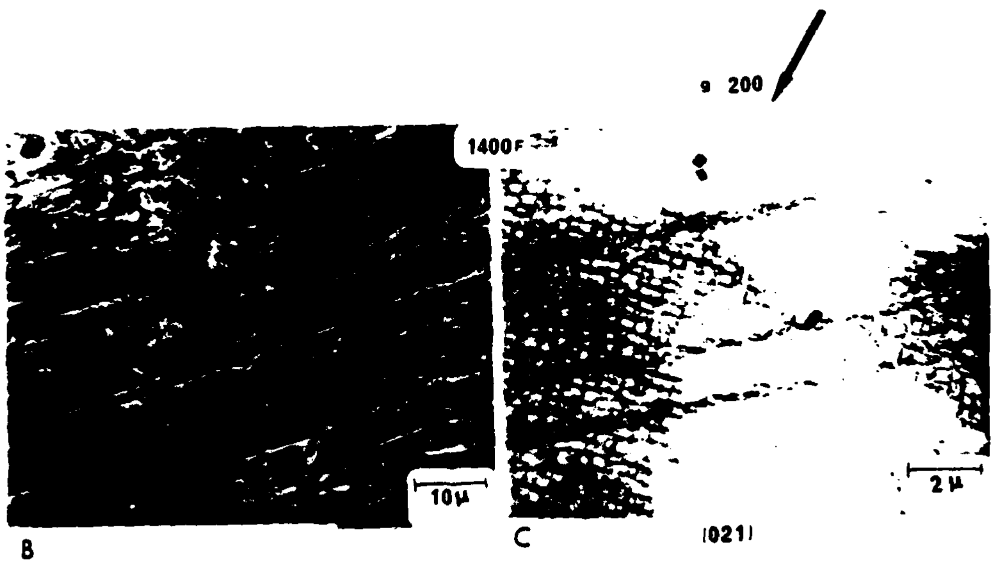

Fig. 3. LCF specimens tested up to 1400F showed slip bands. (A) TEM, 800F, $\Delta\varepsilon_p = 0.1\%$, $N_i = 205$ (493-TT6), (B) SEM, 1400F, $\Delta\varepsilon_p = 0.1\%$, Ni = 930 (494-A4) note oxidized surface, (C) TEM 1400F, $\Delta\varepsilon_p = 0.1\%$, $N_i = 114$, (494-7B2).

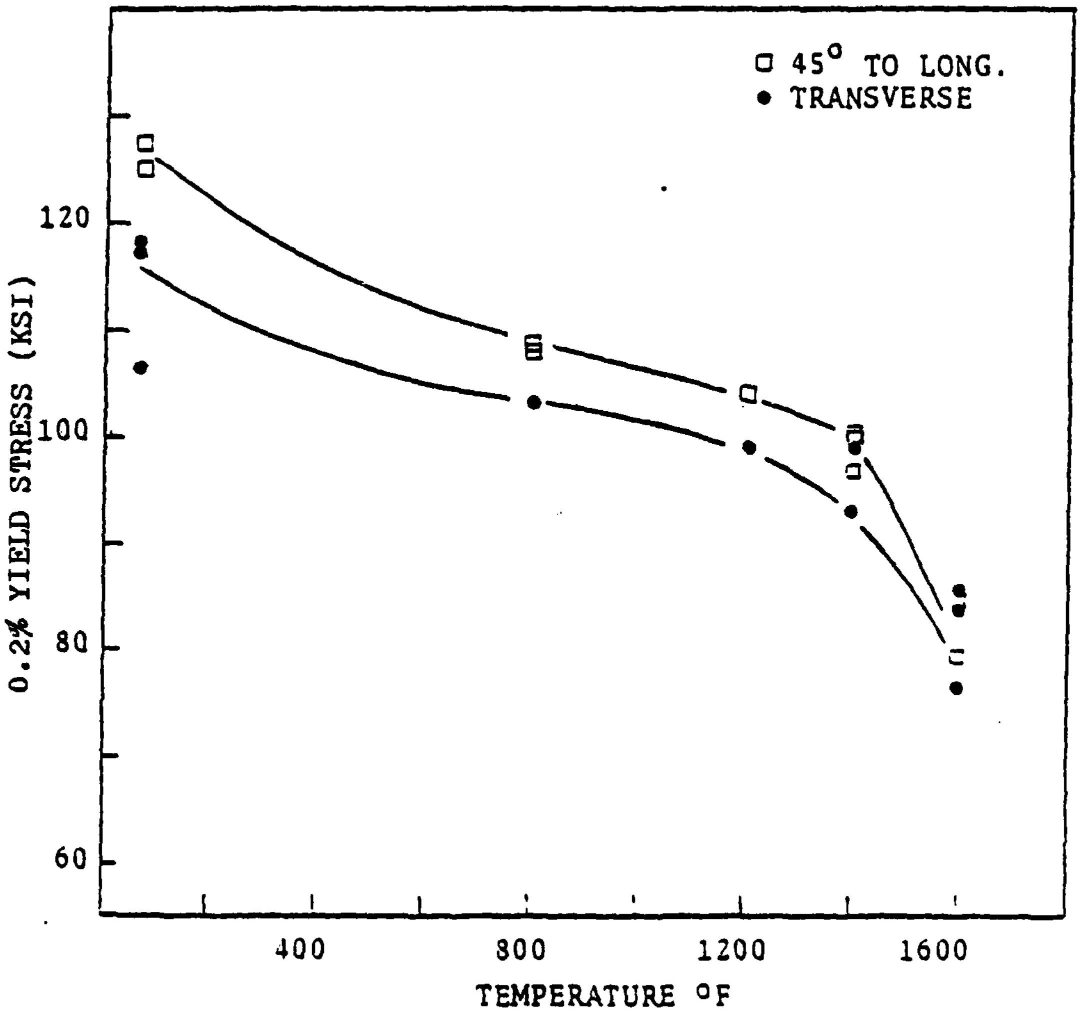

Fig. 4. 0.2% yield stress of DS René 80 as a function of temperature. The yield stress was measured from the first loading cycle.

Fig. 5. Shearing of γ' as a result of planar slip in a specimen tested at 75F, $\Delta\varepsilon_p$=0.25%, N_i=1125 (494-B-7).

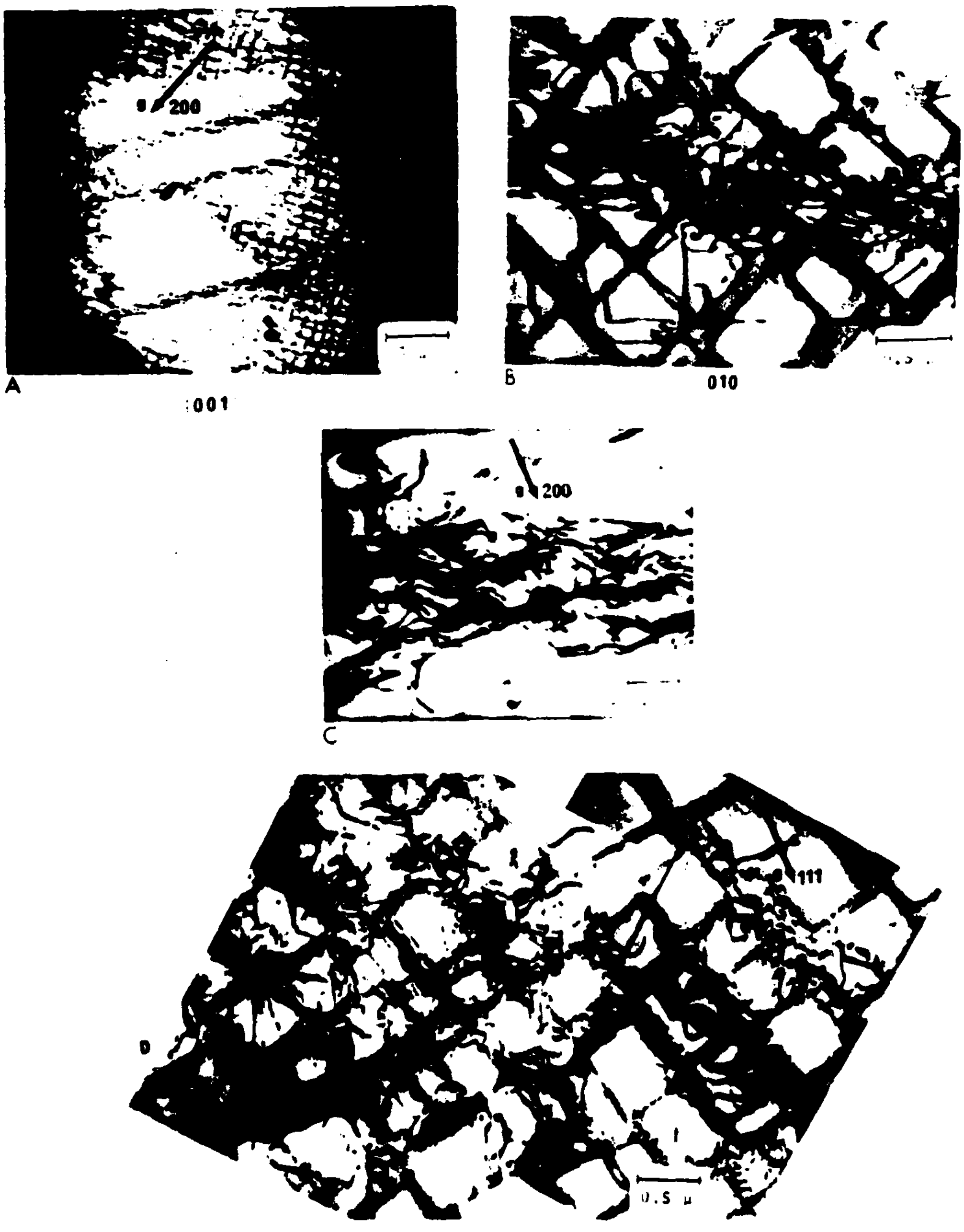

Fig. 6. Planar slip bands formed during LCF testing at 1400°F (A and B). The dislocations are found preferentially in the regions between the large precipitates forming walls around the γ' (C and D). This temperature marked a transition from planar to homogeneous slip. Specimen 493-TB2 $\Delta\varepsilon_p = 0.1\%$, Ni = 114

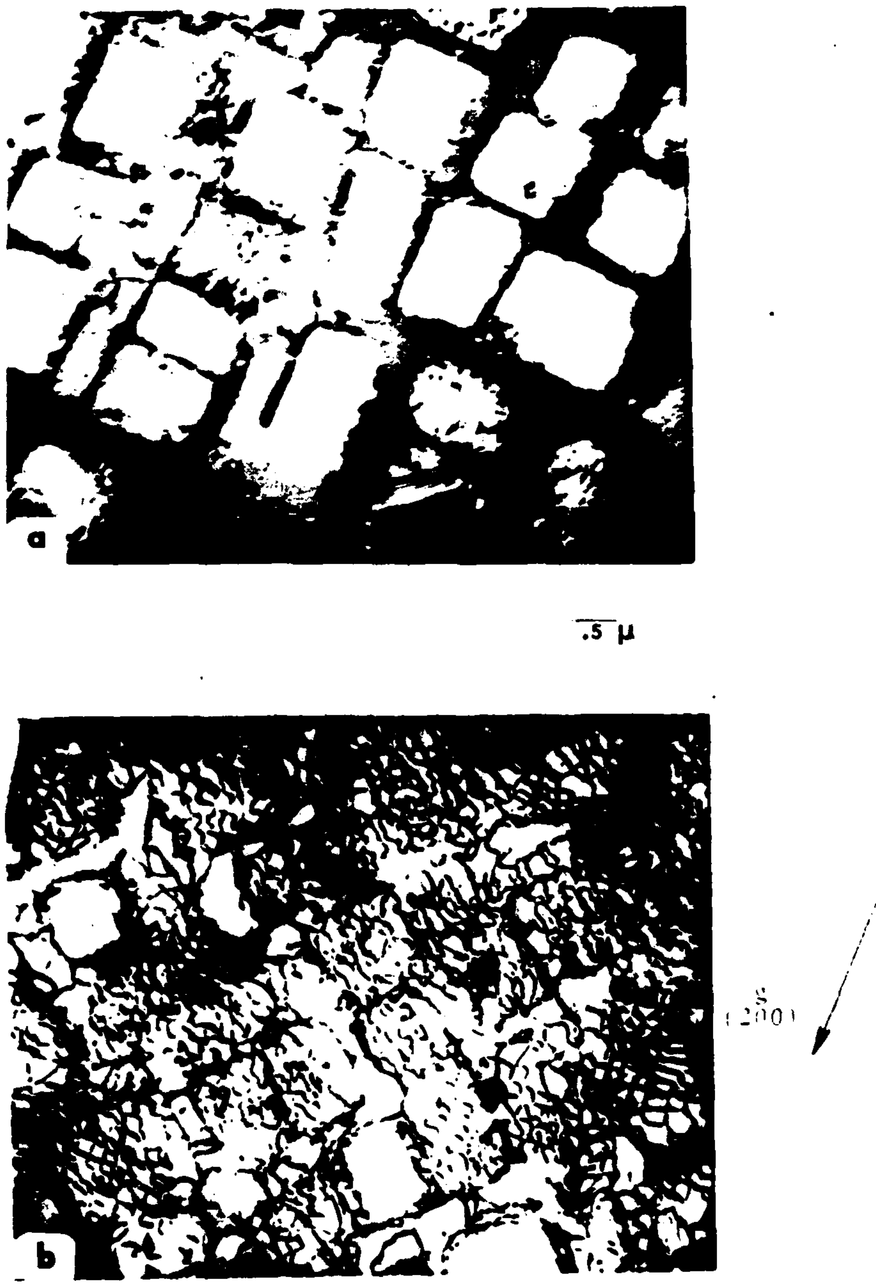

Fig. 7. Typical structure as seen by TEM after LCF at 1600°F. It can be seen that the large cuboidal precipitates have grown while the small ones have disappeared in the dark field micrograph (a), while a network of interfacial dislocations is visible in (b). Specimen 489-LM5 $\Delta\varepsilon_p$ = 0.25%, Ni = 260

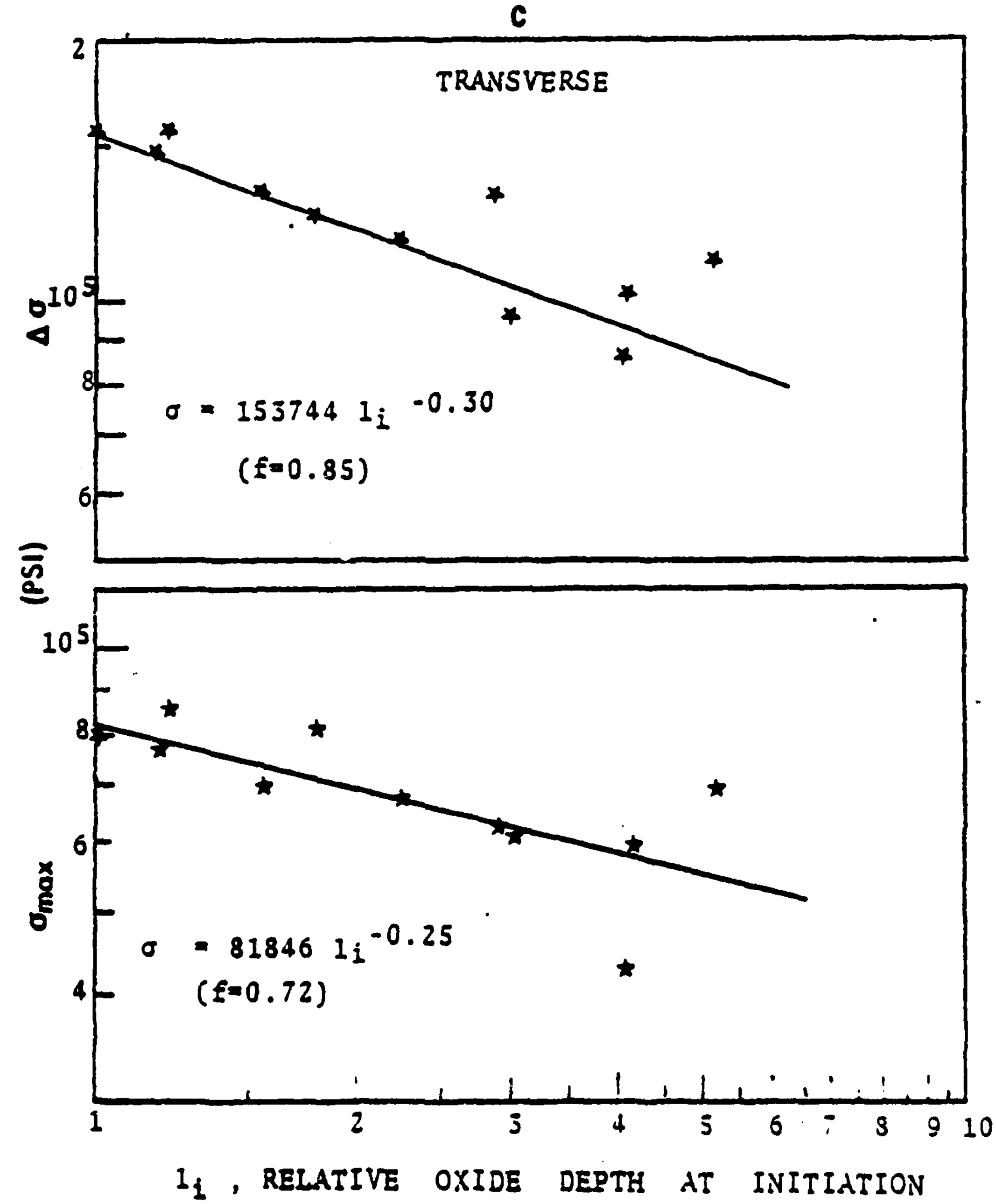

Fig. 8. Stress range ($\Delta\sigma$) or maximum stress (σ_{max}) as a function of the relative oxide depth at initiation for DS René 80 in the transverse orientation. All testing was done at 1600°F.

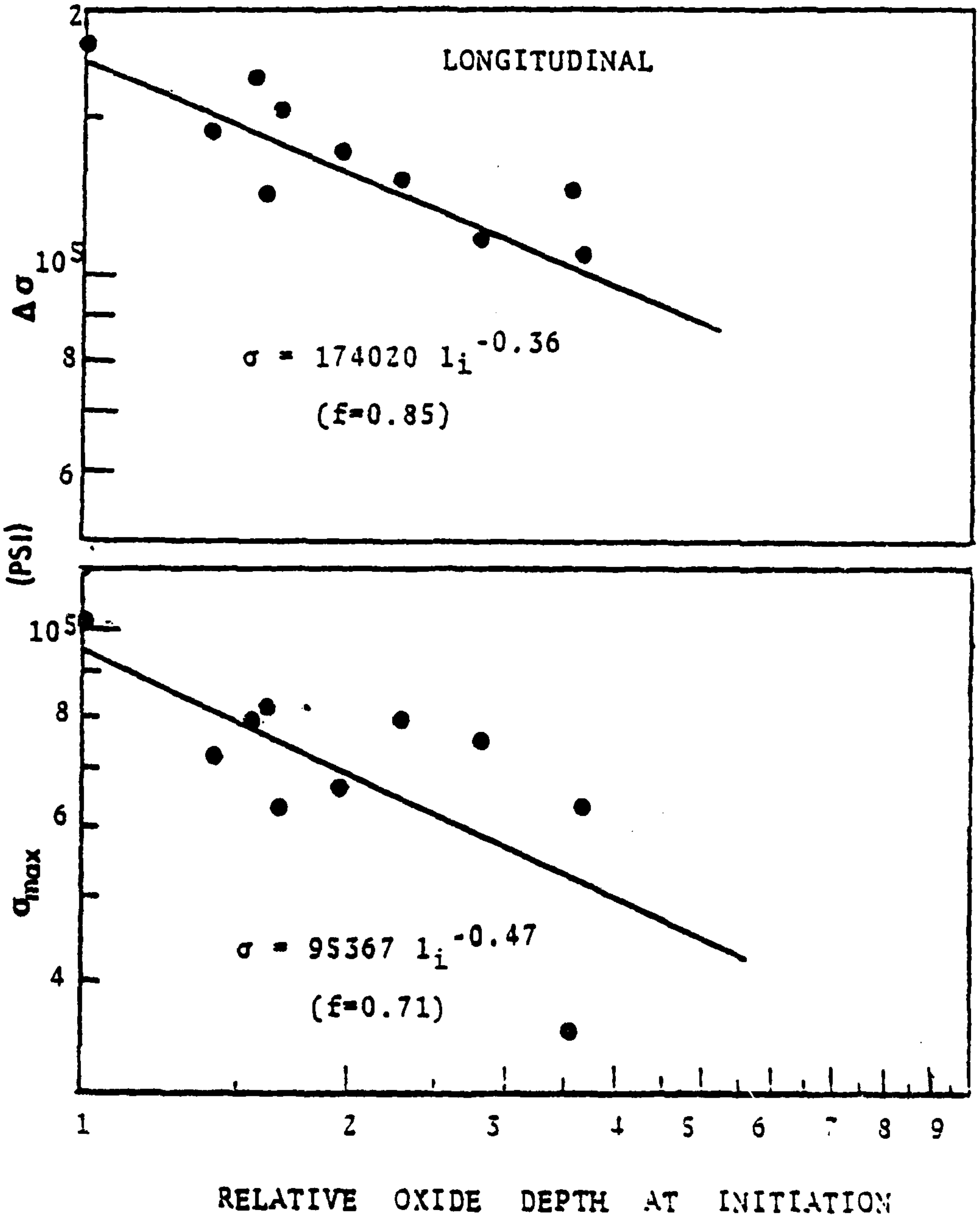

Fig. 9. Same as Fig. 8 except for longitudinal specimens.

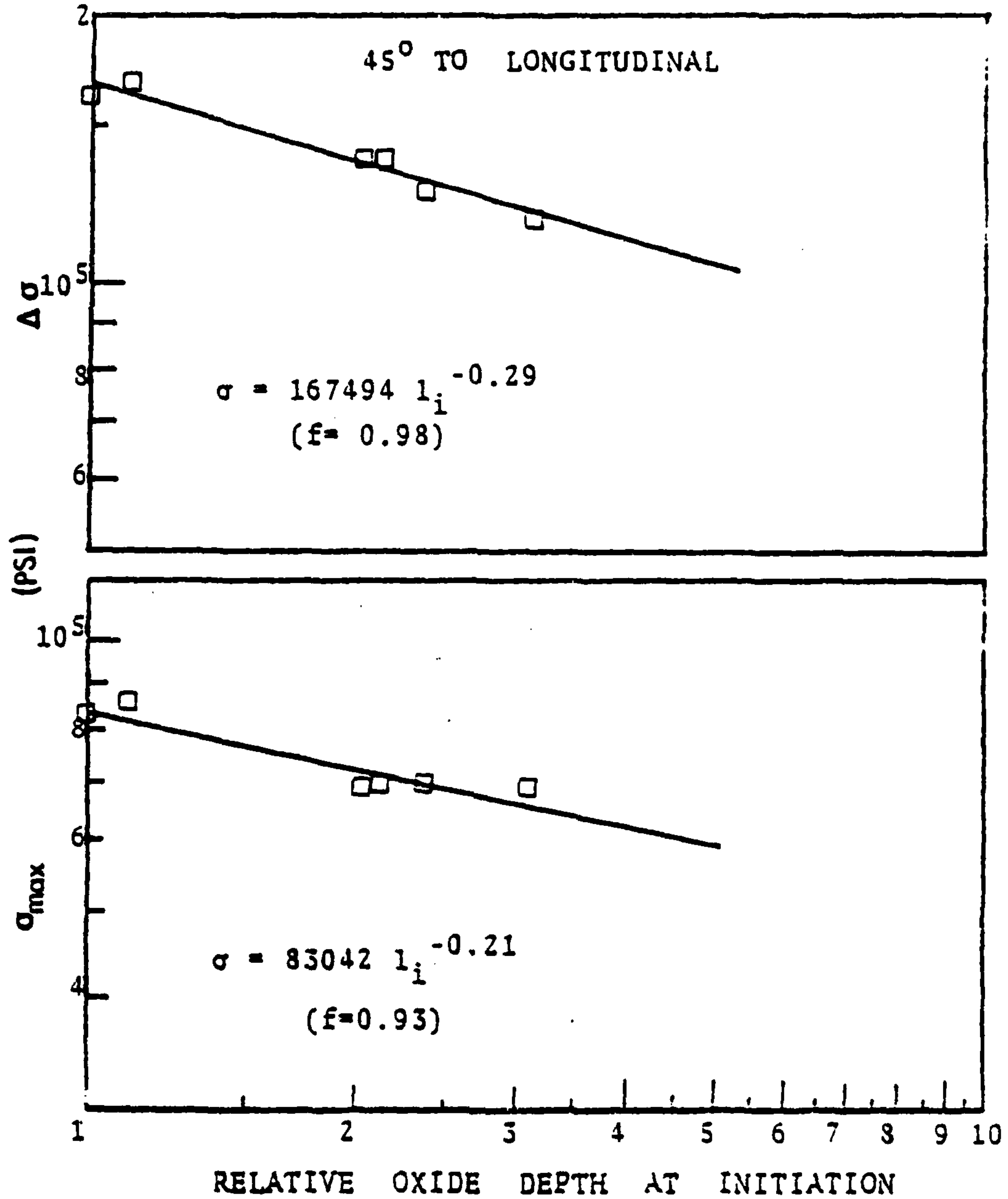

Fig. 10. Stress range ($\Delta\sigma$) or maximum stress (σ_{max}) as a function of the relative oxide depth at initiation for DS René 80 at 45° to longitudinal direction. All testing was done at 1600°F.

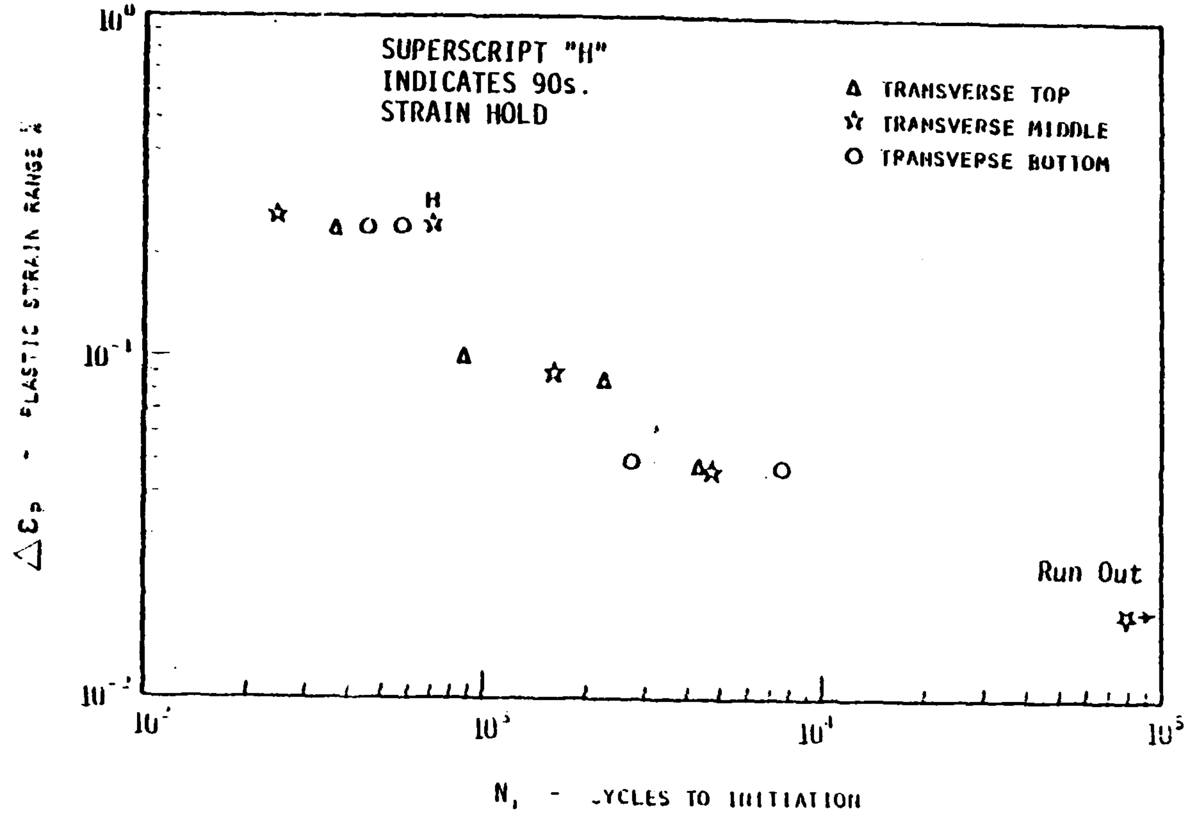

Fig. 11. Coffin-Manson plot of TRANSVERSE specimen data at 1600F. The position in the ingot is noted.

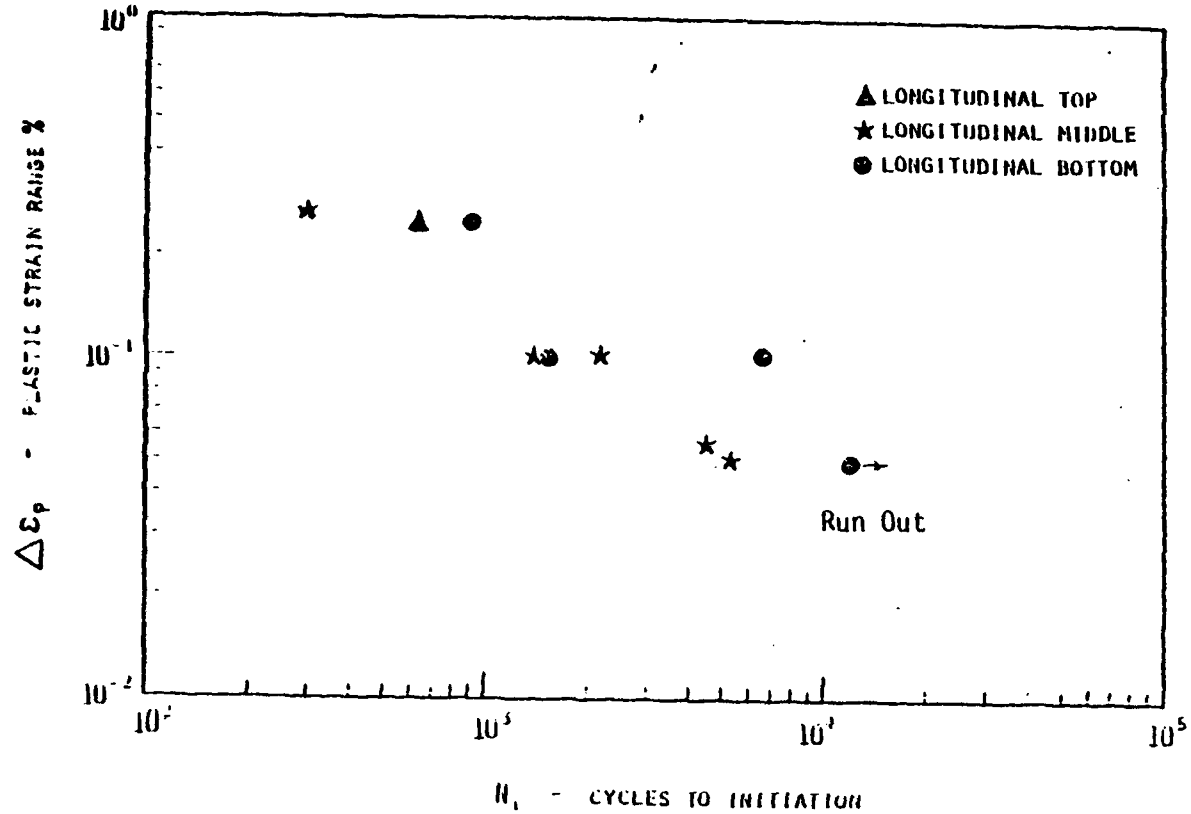

Fig. 12. Coffin-Manson plot of LONGITUDINAL specimen data at 1600F. The position in the ingot is noted.

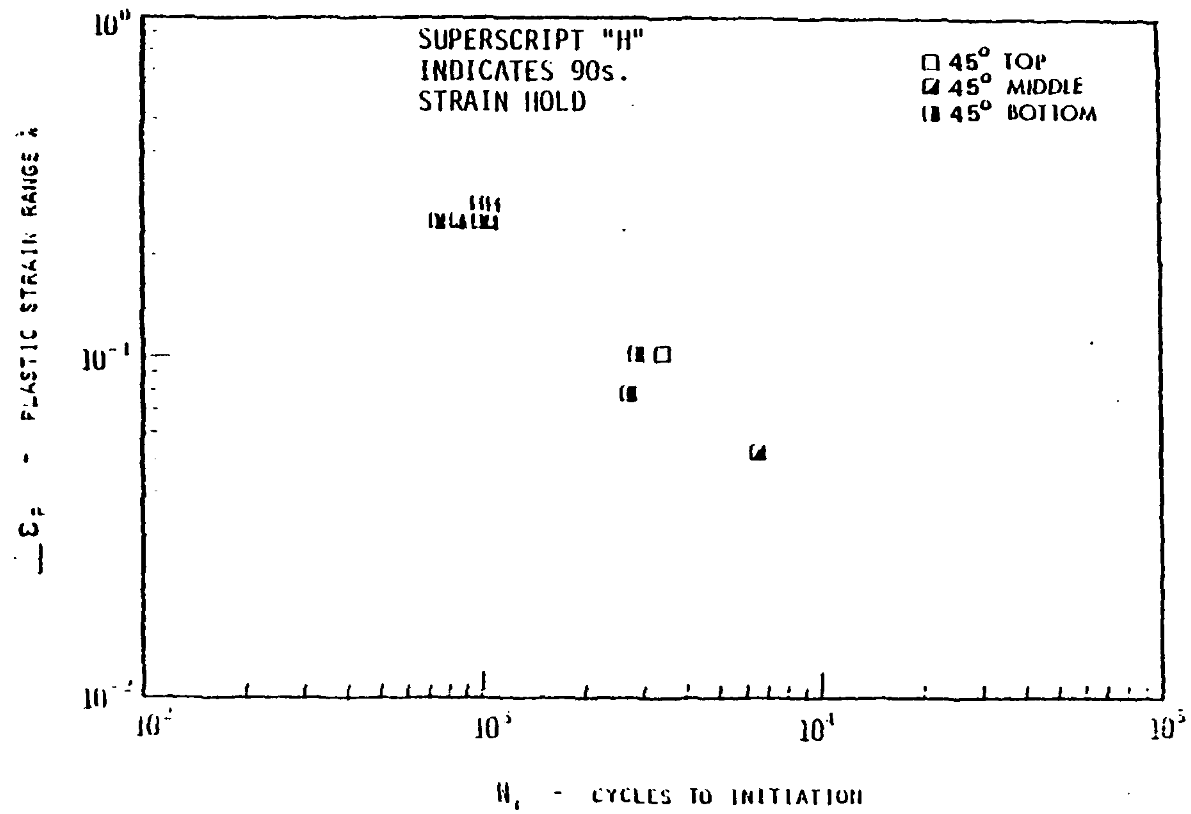

Fig. 13. Coffin-Manson plot of 45° specimen data at 1600F. The position in the ingot is noted.

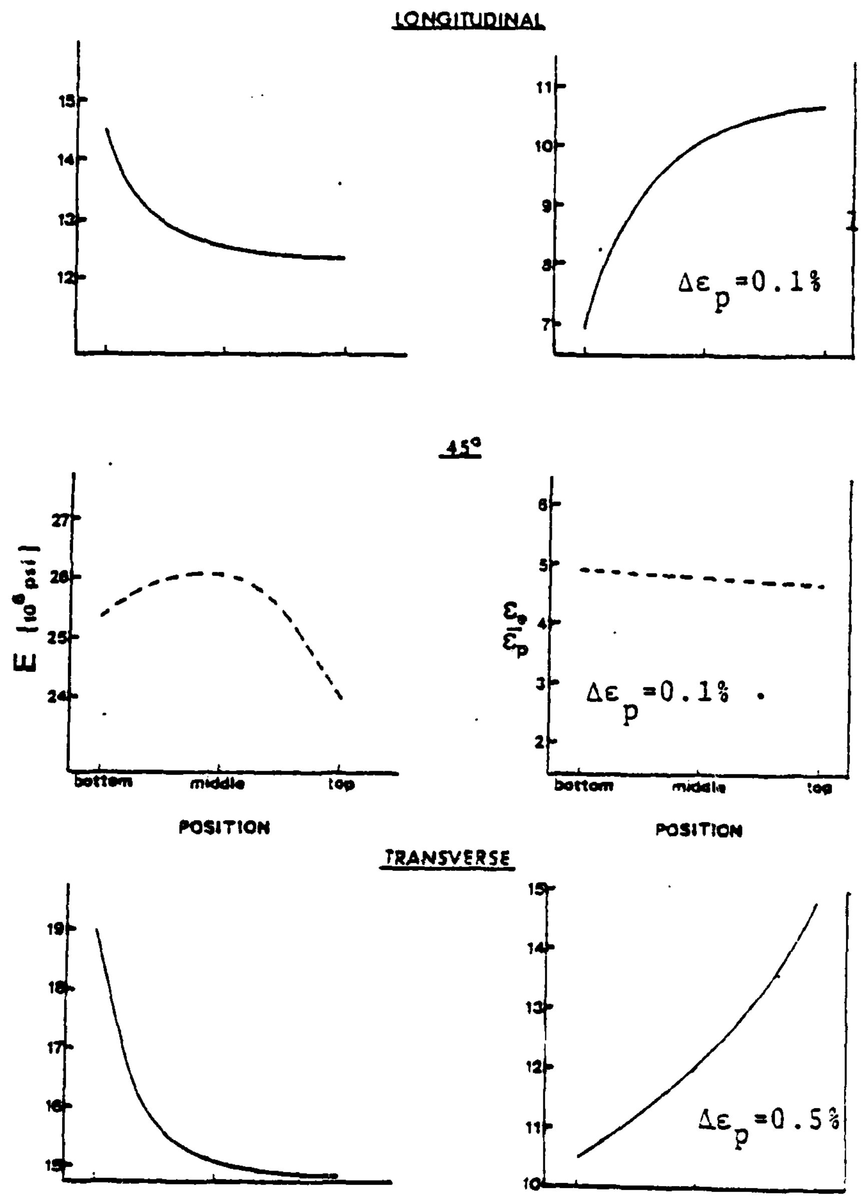

Fig. 14. Effect of location on modulus and the elastic strain associated with a given plastic strain. This behavior appears to be related to the misorientation from the [001] growth axis.

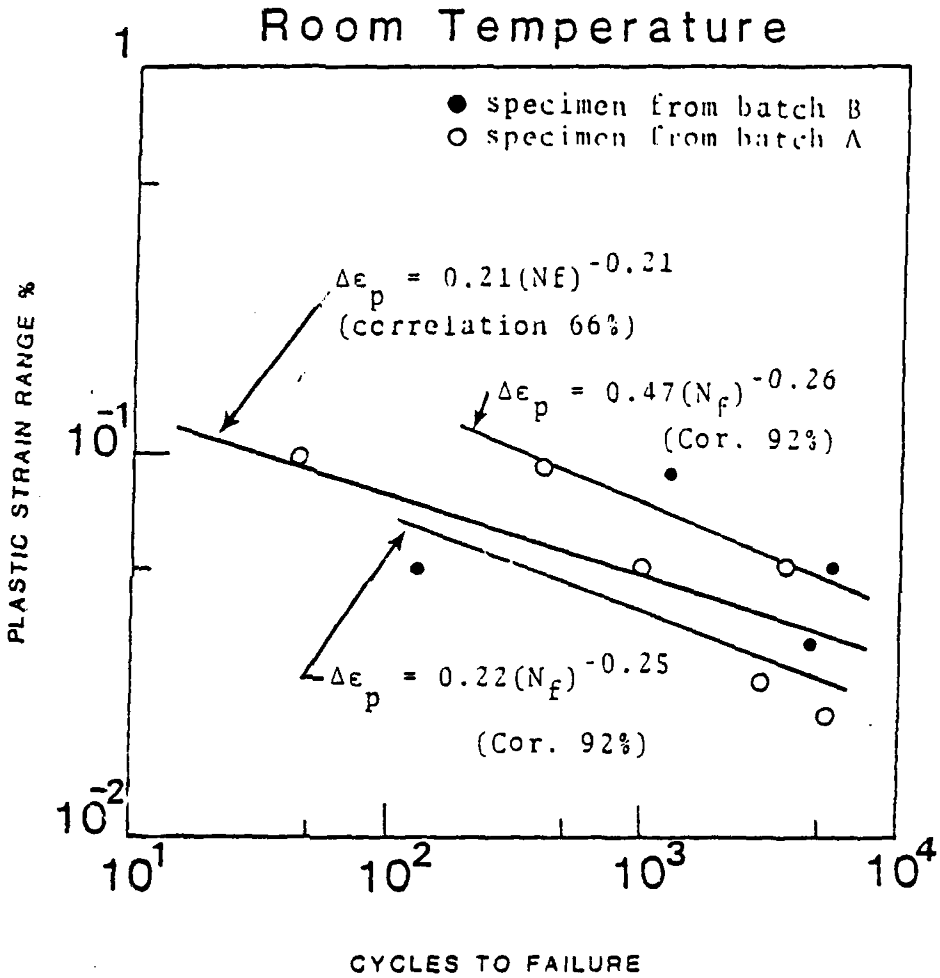

Fig. 15. Coffin-Manson curve (plastic strain range $\Delta\varepsilon_p$ versus number of cycles to failure N_f) for RTLCF specimens. Note the large scatter of the data. This scatter decreases significantly if 2 sets of data are considered; short and long lives

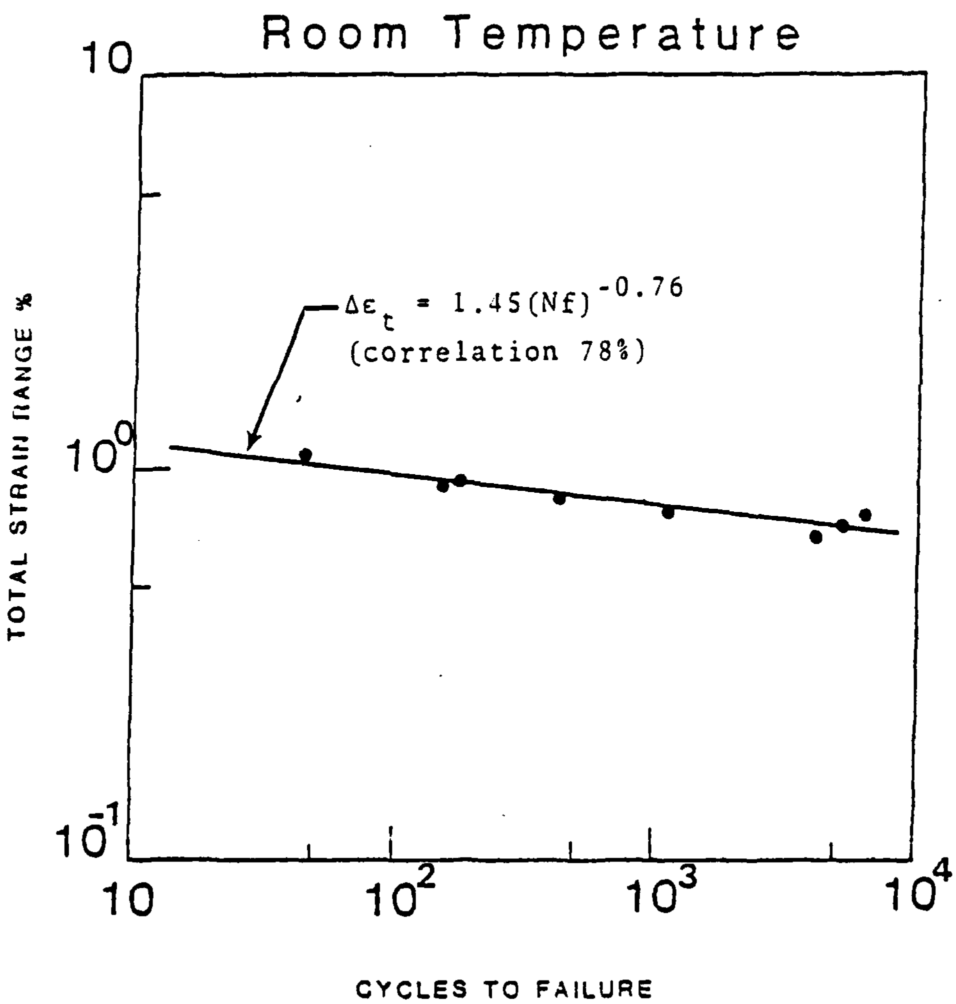

Fig. 16. Plot of total strain range $\Delta\varepsilon_t$ versus number of cycles to failure Nf for RT LCF specimens. Note that the correlation is better than the one obtained from the Coffin-Manson curve in the preceeding figure.

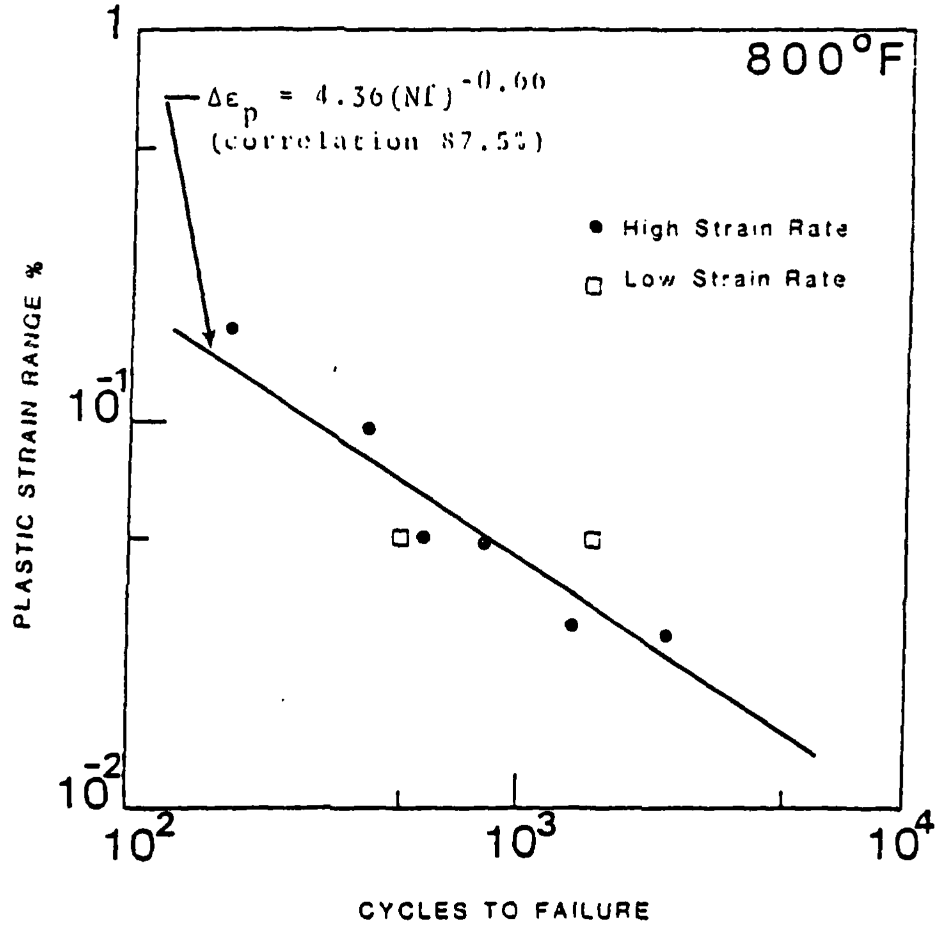

Fig. 17. Coffin-Manson curve, (plastic strainrange $\Delta\varepsilon_p$ versus number of cycles to failure N_f) for 800°F LCF specimens. Note the scatter is minimum for the high rate tests.

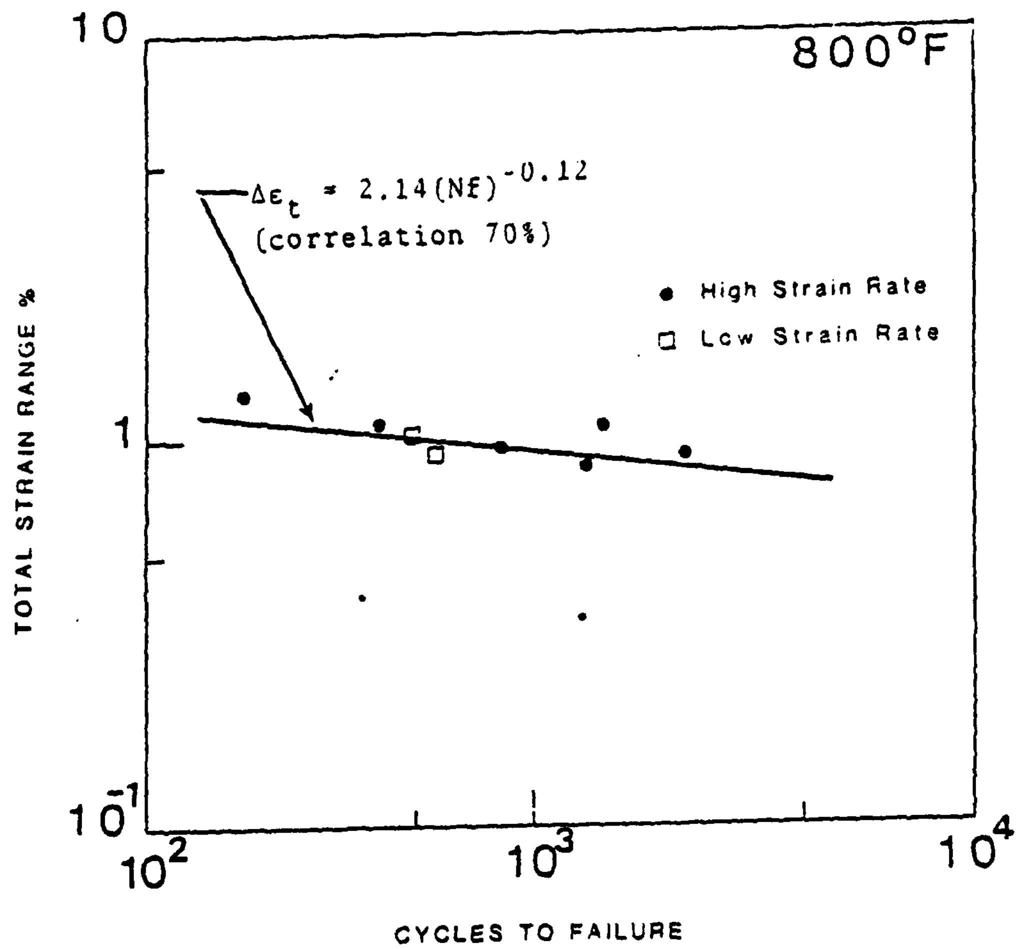

Fig. 18. Total strain range $\Delta\varepsilon_t$ versus number of cycles to failure N_f for 800°F LCF specimens. Note the correlation is lower than for the Coffin-Manson curve.

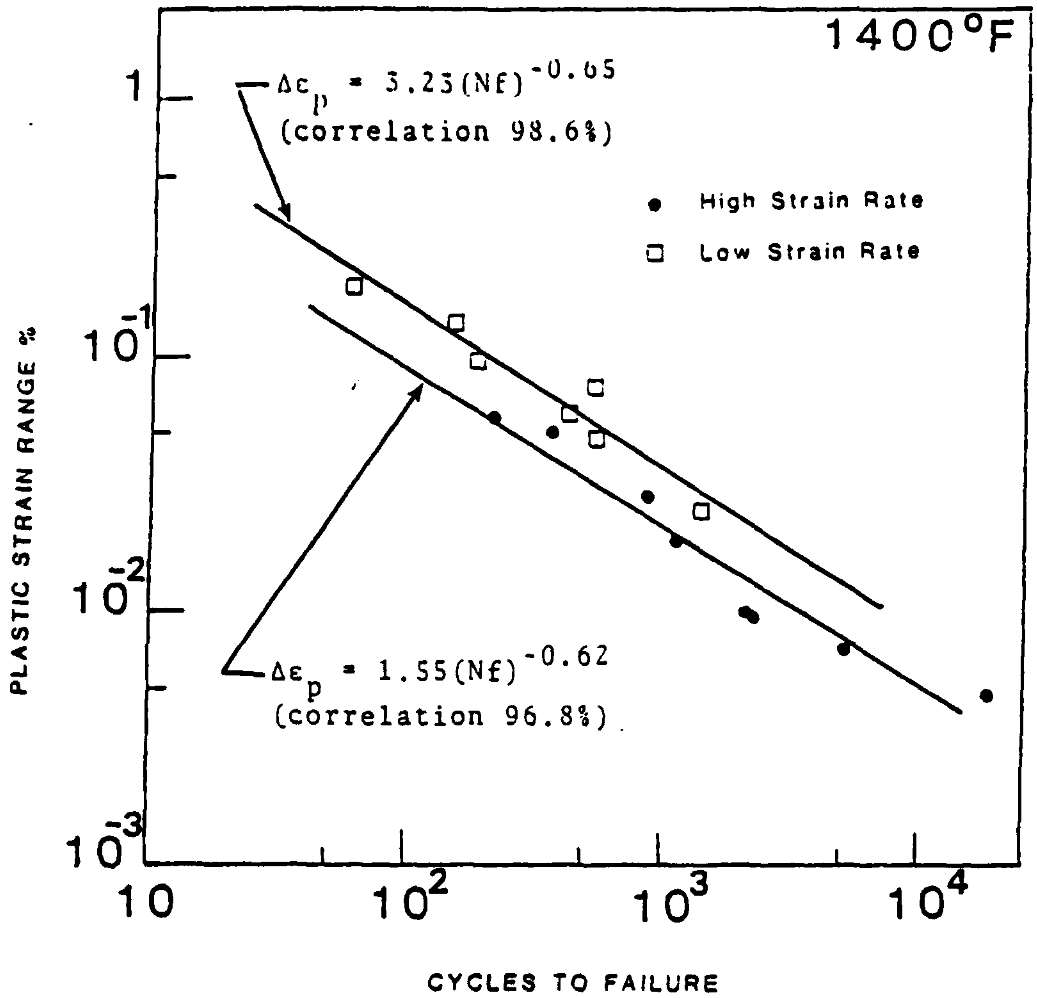

Fig. 19. Coffin-Manson curve, (plastic strain range $\Delta\varepsilon_p$ versus number of cycles to failure N_f) for 1400° F LCF specimens. Note the slight frequency effect.

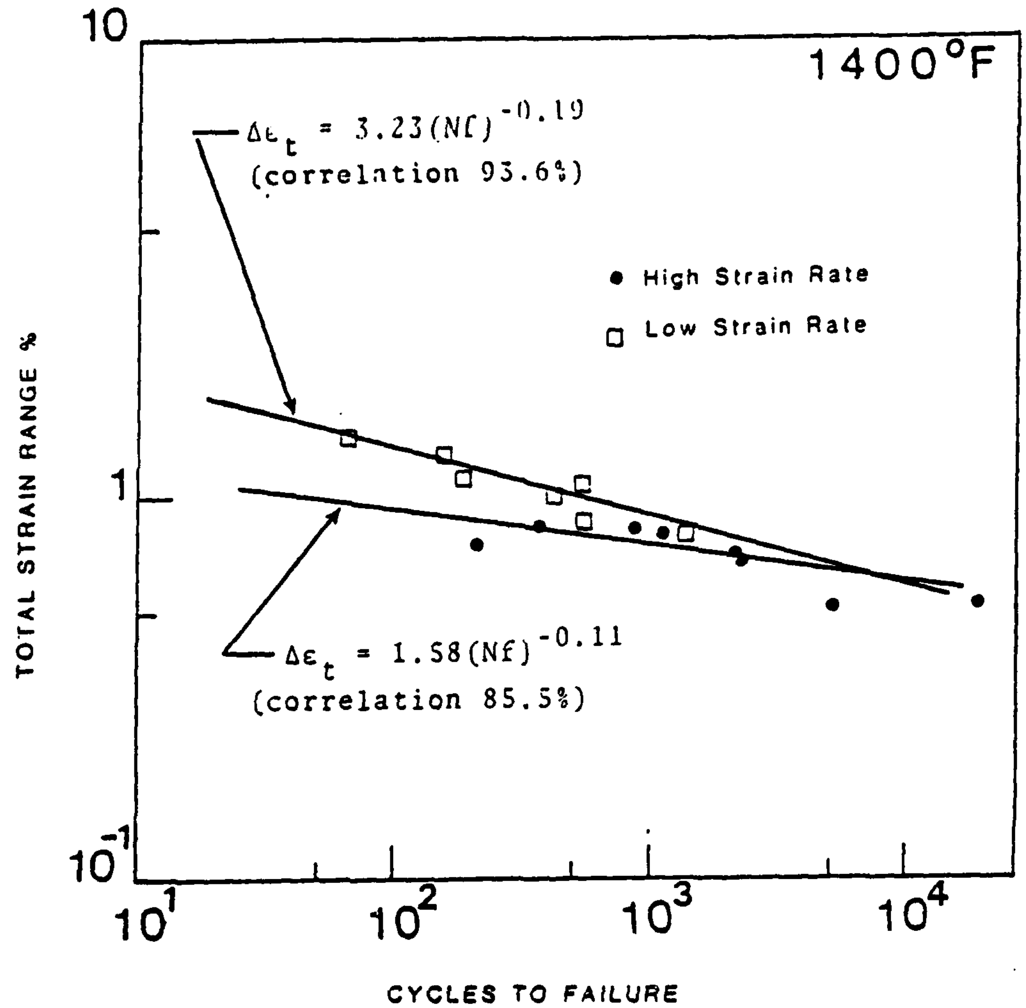

Fig. 20. Plot of total strain range $\Delta\varepsilon_t$ versus cycles to failure N_f for 1400° F LCF specimens.

Fig. 21. Crack initiation at the surface of a 75°F LCF specimen showing a cracked Ti carbide. Note that the cracks did not extend into the matrix nor was there any interfacial decohesion.
Specimen 2H $\Delta\varepsilon_p = 0.055\%$, $\Delta\varepsilon_t = 0.90\%$ $N_f = 372$

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